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SPACE POWER TOOLS

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TECHNICAL MEMORANDUM X-53730

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ABSTRACT

This report is a digest of several technical papers reviewed and combined on the subject of power tools proposed for use in in-space manufacture, assembly, and maintenance operations. Six types of tool power sources were reviewed: (1) electric motor, (2) gas turbine, (3) thermite fueled steam generator, (4) monopropellant powered impulse device, (5) cartridge driven impact devices, and (6) advanced electric motor or brushless dc motor. The brushless dc motor met most safety requirements for use in space environments and is considered to give the most promise for space power tools.

NASA — GEORGE C. MARSHALL SPACE FLIGHT CENTER

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MANUFACTURING ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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SPACE POWER TOOLS

SUMMARY

The description of the tool concepts submitted gives the principle of operation for each tool and the proposed power source. Power output, in watts (horsepower), is presented at the end of each discussion for comparison purposes. The space tools are divided into classes by types of motion and usage. To further investigate space tools, the tool assemblies were divided into three sections, the power source, the prime mover, and the attachments. Advanced electric tools, because of power to weight ratio and safety, are deemed superior to other tool concepts discussed.

INTRODUCTION

The object of this report is to compile pertinent data from investigations on space power tools and describe an optimum power source for operation in a space environment. The majority of the tool concepts require further development and/or modifications to meet the standards for flight rated hardware. With respect to safety and reliability in a space environment, the most promising are electric dc power tools; however, other tool concepts are still under investigation.

In this report, a space tool is divided into three sections

1. Power Source — A source to include power supply.

2. Prime Mover — The section that converts the energy into mechanical motion.

3. Attachments — Those devices which attach to the prime mover section and actually perform the task.

CLASSIFICATION OF POWER TOOLS BY TYPE OF MOTION

This classification categorizes the tools by the type of motion which the tool attachment actually undergoes on the work piece. For example, when we are considering a jig saw, we consider, in addition to the reciprocating motion of the saw blade, the translational motion of the saw itself while it is making a cut. It is this translational motion which puts the jig saw in the translation category. Table I shows the type of motion classification.

TABLE I. TYPE OF MOTION CLASSIFICATION

Translation Type Motion	Rotary Type Motion	Other Plane Motion
Saw 1. Sabre Saw 2. Jig Saw 3. Circular Saw 4. Friction Heat Saw 5. Rotary-Reciprocating Saw (Bone Saw) Chisel 1. Straight Power Chisel (For use by Tethered Astronaut) 2. Nut/Bolt Splitter Welder Shear 1. Reciprocating 2. Rotating - One Wheel 3. Rotating - Two Wheels General Drive Mechanism 1. Use to drive welder or leak detector across wide smooth surface Other	Drill Hole Saw Rotary File Torquing Devices 1. Nut Runner 2. Screw Drive 3. Torque Wrench 4. Aero-Space Fastener a. Huckbolt b. Betabolt c. Hi-Shear Fastener Grinder/Sander Other	Nibbler Pry 1. Porta-Power Driven Expander Impactor 1. Hammer 2. Stud Setter 3. Other Push and Pull 1. Expander-Contractor-Porta-Power Hole Punch Brake/Form Clamp File Riveter Other

Two unfamiliar tool types are given in this classification, the general space drive mechanism and the space porta-power. The general space drive could drive a mass spectrometer leak detector or a shuttle transfer system for the astronaut.

CLASSIFICATION OF POWER TOOLS BY TYPE OF USE

This classification categorizes the tools into groups which would normally be used for in-space maintenance and repair and in-space manufacture.

For purposes of the final power source analysis, a further breakdown of the use of the tool to include two more areas is required: tools/power sources for use within the spacecraft and workshops, and those to be used outside. The fact will develop that the inside tools can be used outside, but the reverse is not true; that is, safety considerations restrict certain tools and power sources to use only outside the spacecraft. Table II outlines this in chart form.

CLASSIFICATION OF POWER SOURCES FOR SPACE TOOLS

The various power sources for space tools are listed (Table III), along with the type of prime mover necessary to transform the power into mechanical output. Available approximate power-to-weight ratios are given in Table III.

DESCRIPTION OF TOOLS AND POWER SOURCES

Electric Motor

A minimum reaction space power tool was developed for the U.S. Air Force in 1963. Development objectives and design criteria of the tool are discussed in Reference 2. The tool is a battery powered electrical motor that will drive various attachments designed for a variety of rotary motion tasks such as nut running, drilling, and sawing. The principle of operation is conversion of the continuous rotary armature motion to an intermediate reciprocating motion, and finally to intermittent, high amplitude rotary motion of the output shaft, all motions being related to the counter-rotating tool body. The tool body is ball

TABLE II. TYPE OF USE CLASSIFICATION

IN-SPACE MAINTENANCE/REPAIR	IN-SPACE ASSEMBLY/MANUFACTURE	SPACECRAFT/WORKSHOP INTERIOR	SPACECRAFT/WORKSHOP EXTERIOR
Translational Type Motion	Translational Type Motion	Translational Type Motion	Translational Type Motion
Saw 1. Sabre Saw 2. Jig Saw 3. Rotary Reciprocating Saw Chisel 1. Power Chisel 2. Nut Splitter Welder Shears 1. Reciprocating 2. Rotating – One Wheel 3. Rotating – Two Wheels	Saw 1. Sabre Saw 2. Jig Saw 3. Rotary Reciprocating Saw 4. Friction Heat Saw 5. Circular Saw Chisel 1. Power Chisel 2. Nut Splitter Welder General Drive Mechanism Shears 1. Reciprocating 2. Rotating – One Wheel 3. Rotating – Two Wheels	Welder Shears 1. Reciprocating 2. Rotating – One Wheel 3. Rotating – Two Wheels	Saw 1. Sabre Saw 2. Jig Saw 3. Rotary Reciprocating Saw 4. Friction Heat Saw 5. Circular Saw Chisel 1. Power Chisel 2. Nut Splitter Welder General Drive Mechanism Shears 1. Reciprocating 2. Rotating – One Wheel 3. Rotating – Two Wheels
Rotational Type Motion	Rotational Type Motion	Rotational Type Motion	Rotational Type Motion
Drill Hole Saw Torquer 1. Nut Runner 2. Screwdriver 3. Torque Wrench 4. Aero-Space Fasteners a. Huckbolts b. Betabolts c. Hi-Shear Fasteners d. Others	Drill Hole Saw Torquer 1. Nut Runner 2. Screwdriver 3. Torque Wrench 4. Aero-Space Fasteners a. Huckbolts b. Betabolts c. Hi-Shear Fasteners d. Others Rotary File Grinder/Sander	Torquer 1. Nut Runner 2. Screwdriver 3. Torque Wrench 4. Aero-Space Fasteners a. Huckbolts b. Betabolts c. Hi-Shear Fasteners	Drill Hole Saw Torquer 1. Nut Runner 2. Screwdriver 3. Torque Wrench 4. Aero-Space Fasteners a. Huckbolts b. Betabolts c. Hi-Shear Fasteners Rotary File Grinder/Sander
Other Plane Motion	Other Plane Motion	Other Plane Motion	Other Plane Motion
Pry Impactor 1. Hammer Punch Riveter Porta-Power Linear Grinder Linear File	Pry Impactor 1. Hammer 2. Stud Setter Punch Riveter Porta-Power Linear Grinder Linear File Brake/Form Nibbler	Pry Impactor Punch Riveter Porta-Power Brake/Form Nibbler	Pry Impactor 1. Hammer 2. Stud Setter 3. Others Punch Riveter Porta-Power Linear Grinder Linear File Brake/Form Nibbler

TABLE III. TYPE OF POWER SOURCES FOR SPACE TOOLS CLASSIFICATION

Electrical Power	Gas Power — Continuous/Pulsed	Single Shot Gas Power Source
<u>Power Source</u> 1. Batteries* a. Primary (One Shot) [110 Whr/kg (50 Whr/lb)] b. Rechargeable [143-220 Whr/kg (65-100 Whr/lb)] Silver Zinc 2. Fuel Cells [880 Whr/kg (400 Whr/lb)]* a. Alone b. With Batteries 3. Solar Panels with Batteries [8.8-26.4 Whr/kg (4-12 Whr/lb)]* 4. Chemical Powered Mechanical Generators [660 Whr/kg (300 Whr/lb)]* 5. Nuclear-Electric Generators (Thermionic/Thermoelectric) 6. Other <u>Prime Mover</u> 1. DC Motor 2. AC Motor 3. Magnetomotive Forming Devices	<u>Power Source</u> 1. Monopropellant Gas Generator 2. Biopropellant Gas Generator 3. Solid Propellant Gas Generator 4. Thermite-Steam Generator 5. Nuclear Steam Generator 6. Other <u>Prime Mover</u> 1. Turbine 2. Axial Piston Motor 3. Other	<u>Power Source</u> 1. Solid Propellant Cartridges 2. Monopropellant Cartridges 3. Thermite-Steam Cartridges 4. Other <u>Prime Mover</u> 1. Turbine 2. Axial Piston Motor 3. Single Piston Impactor 4. Other

* Data taken from Reference 1.

bearing and mounted in the handle, which also contains a nickel-cadmium battery. A maximum reaction torque of 6.4×10^{-3} m-N (0.9 in.-oz) occurred during 27.12 m-N (240 in.lb) torque output which exceeded the U.S. Air Force criterion of 20.34 m-N (180 in.-lb). Subsequently, NASA-MSC funded a program for a "Space Tool Survey Development and Evaluation Program" to:

1. Define the requirements for design of space tools.

2. Define the interface requirements between the tool systems and the worker.

3. Fabricate a prototype tool kit based upon the requirements established at the beginning of the program.

Under the NASA-MSC contract, development work done previously under the U.S. Air Force Contract was used as a point of departure. The prime mover section was defined, the various attachment sections were developed and tested, a battery (silver-zinc) was selected, and the complete tool kit was developed. The principle of operation was unchanged. The battery location was moved from the tool handle to a remote kit because of its size and weight increase from 0.454 to 2.28 kg (1 to 5 lb). The maximum reaction torque output is 115.25 m-N (85 ft-lb) with 4.2×10^{-2} m-N (6 in.-oz) reaction; the NASA-MSC goal was 101.69 m-N (75 ft-lb) with 1.4×10^{-2} m-N (2 in.-oz) reaction during impacting.

Gas Turbine

Reference 4 is a description of a preliminary design and not a proven hardware item. It is entitled "Technical Description of a Minimum Reaction Space Tool." The principle of operation of this tool is similar to that of the electric motor tool.

The principal design difference is that this prime mover is a two stage axial flow turbine driven by high pressure gas, hot or cold, from an external source. The electric motor tool has mechanical bearings between the handle and the tool body which give rise to reaction torque caused by the friction. This is virtually eliminated in this tool by using some of the high pressure gas for main bearings.

The turbine speed is made variable by controlling the inlet gas valve with a trigger. Output shaft torque was calculated to be 59.66 m-N (44 ft-lb) for assumed design and inlet conditions of 3 447 378.6 N/m^2 (500 psi) and 449.4°K (350°F) with a mass flow through the unit of 0.005 kg/sec (0.011 lb/sec).

Thermite Fueled Steam Generator

The information available briefly describes a conceptual design of a space power tool which has a steam generator for the space module [5]. The thermite fuel is contained in an expendable fuel cartridge which is inserted into the hand-held tool. Upon ignition, the heat of reaction 3 719 111 joules/kg (1600 Btu/lb) is transferred into steam boiler tubes located around the cartridge chamber. The steam at approximately 1 378 951 N/m^2 (200 psi) and 699°K (800°F) is throttled into an energy converted (an axial-piston motor). After leaving the motor, the steam passes through condenser tubes on the outside of the tool and then enters the reservoir as water. The output shaft power is varied by controlling a steam by-pass valve with a trigger. The power output is specified to be from 186 to 373 W (0.25 to 0.5 hp) with a fuel consumption of 4.54 kg/hr (10 lb/hr).

Monopropellant Powered Impulse Device

Reference 6 is a technical description of a space tool conceptual design. This document does not emphasize minimum reaction operations; basically, it presents a power module and prime mover concept and not an entire tool.

The power module is actually a hand-held gas generator to which various working heads can be attached, utilizing liquid monopropellant (hydrazine) as a fuel. The power module consists of a propellant supply, combustion chamber, igniter, appropriate valving and controls, and a means for precision adjustment of charge size. The attachment modules contain different types of prime movers as well as the mechanism required to convert the rotary or linear output of the prime mover into the desired output.

The shaft output is calculated to be 11 185.5 to 14 914.0 W (15 to 20 hp) for 5 to 10 seconds, producing 40.95 m-N (30.2 ft-lb) of torque at 3600 rpm for a hydraulic motor.

Cartridge Driven Impact Devices

The information provided in the document describing this concept consists of photographs and a brief description of 5.6 mm (22 caliber) cartridge powered tools which have been built for industrial applications [7]. No suggestions were made toward an approach for applying a cartridge as an energy source for a minimum reaction space tool; however, such a tool is feasible, and a prototype cartridge actuated tool is being evaluated at the present time. A second type is being developed by MSA to include other operational features.

Advanced Electric Tool

This is the result of an inhouse effort to determine the type of power source that would be the safest and most reliable for operations in space. The brushless dc motor was developed originally for satellite application. The results of this investigation and development effort are reported in Reference 8.

The brushless motor is battery powered and is being designed to drive an impactor type space tool and also to drive various attachments for tasks such as sawing, drilling, and nut tightening. In the brushless motor, the commutator function is duplicated by a solid state electronic switching system that eliminates the sliding contacts. The brushless unit uses a permanent magnet rotor for field excitation and a slotted stator with a conventional dc armature winding. The current in each coil of the armature winding is reversed by a solid state power switching network [8]. Switching for the electronic commutation process in the motor is provided by solid-state photo devices which are activated by a rotating beam of light. The output is calculated to be approximately 746 W (1 hp), producing 0.005 m-N (0.67 in.-oz) torque at 3000 rpm with input power of 3 W at 24 Vdc.

EVALUATION OF THE VARIOUS POWER SOURCES

Each power source was evaluated using the same criteria as information was available.

Safety

Temperature. Any part of the space tool which could come in contact with the astronaut must not become hotter than 394°K (250°F) nor colder than 116°K (-250°F) during the longest expected use of the tool [9]. The temperature of the tool should preferably not come close to either of these extremes for extended use; probably 294° ±28°K (70° ±50°F), or from 266° to 322°K (20° to 120°F), would be safer and impose less load on the space suit environmental control system. In addition, the exhaust products must lie within this temperature range if there is a chance that they might impinge upon the astronaut.

Exhaust Products. The exhaust must be noncorrosive and non-contaminating if there is chance of its impinging upon the astronaut or upon a part of the spacecraft where it could cause damage by corrosion or become a source of contamination. In addition, if the tool is used within the confines of the spacecraft pressure cabin, the exhaust gases must be nontoxic and impose no additional load upon the environmental control system. In effect, this rules out all gas powered or gas producing power tools for use within the spacecraft. Thus, for internal cabin use, we are already restricted to electric power or possibly thermite-heated steam power if the exhaust steam is retained within the tool.

Spent Fuel Disposal. If fuel cartriges are used, some provision must be made for their safe disposal. If, as in the case of thermite fuel cartridges, they are extremely hot, they must either be allowed time to cool, or be disposable and storable without having the astronaut come in contact with them. If the spent cartridges are stored in the spacecraft, they must be resealed to insure that no spent material gets loose in the cabin. If there is a possibility of any material getting out, the toxicity of the spent cartridge must be considered.

Ejecta Caused by Exhaust. The space tool power source must be designed so that its exhaust does not blow chips or cuttings away from the work site. It also must not damage adjacent equipment, wiring, and so on.

Cable Fouling. If there is a cable or hose connecting the tool to either a remote power source or the astronaut, the possibility of fouling this cable must be considered. The effect of cutting or pulling loose this cable or hose on the astronaut's safety must be evaluated. For example, in the case of a hydrazine-powered tool with a remote tank, cutting of the hydrazine line would result in contamination and possible blinding of the astronaut. A suitably armored hose could be provided, but at a substantial weight penalty.

Handling of Fuel. If the fuel is toxic, corrosive, or contaminating, either it must be in sealed containers or provision must be made for remote filling of the supply tank. For example, if the hydrazine from the maneuvering unit is to be used, all connections must assure no possibility of leakage during a filling operation.

Total Power and Power to Mass Requirements

Storage Volume to Weight for Used and Unused Fuel. In the case of packaged fuel, the weight and volume of the fuel cartridges makes the theoretical power to weight to volume ratio worse. If the used fuel cartridges are retained, storage space must be provided for them, possibly in the same area where the unused cartridges were stored. It is obvious that packaged fuel does not offer as attractive a solution to extensive space work as does bulk fuel, at least as far as weight and volume are concerned.

Power to Mass Ratio. Naturally, the system with the highest power/ mass ratio is the most attractive from the standpoint of launching it. Ultimately, the power/mass ratio will be one of the major deciding factors in the evaluation of a candidate space power tool system.

Recharge Capability. Provisions must be made to insure that the power supply, when depleted, can be recharged. For the case of batteries, suitable chargers must be supplied, powered by either solar cells, fuel cells, or other available means. The fuel cells must be kept supplied with fuel, and replacement batteries must be stocked. If the space tool is a self-contained hydrazine-powered unit, for example, a refill capability must be designed in for any extended use period. For long term usage, bulk loading of the monopropellant has advantages over cartridge loading, but both types must be considered. Certain systems naturally lend themselves more readily to recharging than others.

Other Considerations

Emergency Power Source. In case of an emergency power failure, the space tool should be useable, but this may not be a realistic situation. Generally, a major power failure on a spacecraft would so jeopardize the mission that the chance of such a failure must be minimized by having redundant power systems. It may not, therefore, be realistic to consider performing operations under a condition of power failure. It would amount to an unnecessary capability, although most of the tool systems proposed would work, at least for a short time, without spacecraft power. A completely packaged power tool system, such as the thermite system, might be considered to have an advantage here, but it is slight. Both the electrical system and the hot gas system require spacecraft power for recharge — either battery recharge or electrical power to open valves. So far there are very few hand operated valves on any existing spacecraft.

Availability of Power Source on Existing Spacecraft. Part of the recharge/use capability of a space power tool system depends on power supplies or fuel being normally aboard the spacecraft — either fuel/solar cells for battery recharging, or monopropellant fuel for the gas generator powered tool. The advantage of using existing power or fuel is that existing systems can merely be increased in size rather than duplicated, a situation which will cause a significant weight reduction. The increased capability system will, in general, weigh less than the duplicated system.

Other Uses of the Power Module. Other (non-direct tool) uses of the power module can often aid in the completion of a mission. As an example, a gas generator power supply could provide gas for an inflatable structure if the exhaust gases were compatible with the structure materials and possible habitation restrictions. Direct electric power is necessary for lighting, but could also be used to heat restraint attachment adhesives or to power magnetomotive forming, punching, or fastening tools.

Minimum Reaction Requirements. Gas-powered tools must be designed in such a way that the exhaust gases do not generate reaction forces. Such power tools can present a very difficult design problem. Naturally, electric tools, having no exhaust gases, do not present this problem.

DISCUSSION AND ANALYSIS

General

For a tool system to be useable within the cabin, it must meet the following requirements; absence of non-life-supporting exhaust gases; no severe temperature load imposed on environment system; and no chips, cuttings, or ejecta. These requirements eliminate the gas-powered tools (exhaust gases and temperature), the thermite steam-powered tools (temperature), and the cartridge powered tools (exhaust gases). The use of saws, drills, files, sanders, chisels, and grinders is eliminated because of the chips and cuttings. A tool using chemical bonding can also present a problem because of the fumes. We are thus led to the conclusion that only electrical power (either from sealed batteries or from an external power source — fuel cell, reactor, etc.) or hand power will be safe for use within the spacecraft, and, furthermore, certain tools must be prohibited because of chips, cuttings, ejecta, and so on.

The result of this restriction on power tools for interior use leads us to three choices for tool system power:

1. Use no power tools in spacecraft interior. Redesign existing hand tools and tether systems to do a better job in the zero-gravity environment. Since for most jobs within the spacecraft a spacesuit will not be necessary, hand tools can be used more easily. The power tool with the best power/mass ratio can then be chosen for the outside tasks. The advantage of this approach is that only one power tool system need be developed. The disadvantage is that no power tools are available for inside work.

2. Use only electrical power tools that are suitable both inside and outside the spacecraft. The advantage of this is that only one power tool need be developed, and it can be used anywhere; the disadvantage is that for long term usage, other power tools may have a better power/mass ratio.

3. Use electrical power inside and whichever unit gives the best power/mass ratio outside. This approach could have a weight advantage over the second alternative for sufficiently long missions. The disadvantage is that two power units need to be developed. We next need to consider the point at which the weight of some advanced power tool system plus an inside electrical system crosses over a pure inside-outside electrical system.

First we briefly consider the power cord problem. For a gas generator system to have significant weight advantages, it must make bulk use of the generant. This means a remote tank and pressurization system (since a remote gas generator and hot high pressure gas line is less attractive than a cold generant pressure line from a source to a generator mounted on the space tool). It seems reasonable to assume that an electrical wire will present fewer problems than a pressure hose since it can be made smaller, less subject to damage, and thus safer and more flexible.

We assume that both electrical power and monopropellant will be available on the spacecraft or on the S-IVB Orbital Workshop, and that furthermore we need not consider a major electrical power failure as this is such an extreme case as to constitute a mission failure. In any case, both a battery-powered tool and a propellant gas-powered tool would be useable as long as their self-contained power lasted. Probably neither could be recharged in the event of a power failure.

We concluded previously that 186 W to 373 W (0.25 to 0.5 hp) would be adequate to power all the candidate tool modules, and that a rotary type prime mover offered advantages over other types in that it was capable of driving the largest number of tools. We will therefore consider candidate power systems which are capable of producing approximately 186 W to 373 W in a rotary device.

Candidate Systems

1. Electric Motor [3]

   a. Specifications

      Weight of Power Supply: 2.21 kg (5 lb)

      Weight of Prime Mover: 2.56 kg (5.62 lb)

      Power Supply Capacity: 163 W-hr

      Power to Weight of Power Supply: 71.7 W-hr/kg (32.6 W-hr/lb)

      Type of Power Supply: Commercial silver-zinc rechargeable batteries.

      Type of Prime Mover: Permanent magnet 12-Vdc motor with minimum reaction features.

   b. Computations

      Use time to depletion: at 373 W (0.5 hp) — rate, 1572 seconds or 26.2 minutes; at 746 W (1 hp) rate, 786 seconds or 13.1 minutes; or 586 356 W-sec (786 hp-sec), 9773 W-min (13.1 hp-min).

2. Gas Turbine [4]

a. Specifications

Weight of Power Supply: unspecified

Weight of Prime Mover: 2.3 kg (5.15 lb)

Power Requirements: 0.0051 kg/sec (0.0112 lb/sec) gas flow at 3 447 378.6 N/m^2 (500 psig) and 449.4°K (350°F). This assumes $\gamma = 1.33$, R = 448.02 m-N/kg/°K (83 ft-lb/lb/°R).

Power Output: The turbine produces approximately 438 W (0.587 shaft hp) at 25 750 rpm. This is reduced to 377 W (0.505 hp) and 45 rpm in the reduction and reversing gears.

Type of Power Supply: unspecified type of gas generator.

Type of Prime Mover: two-stage axial-flow turbine with reduction gear and gas bearings.

b. Computations

If we assume a monopropellant hydrazine gas generator with the low turbine inlet temperature, our molecular weight will be about 11. This changes R to approximately 756 m-N/kg/°K (140 ft-lb/lb/°R) and changes the mass flow rate to 3.9 grams/sec (0.00862 lb/sec). This results in a flow rate of 7.84×10^{-4} moles/sec or 0.00797 m^3/sec (0.2815 SCF/sec). If we assume that for a sufficiently large gas generator we can get 1.247 m^3/kg (20 SCF/lb) of gas generator [10], we get 6.4 grams/sec (0.01407 lb/sec) for 377 W (0.505 hp). This looks extremely unfavorable for this candidate, but two things should be noted before we reject it completely. First, the turbine performance could be greatly improved by using a higher inlet pressure and, second, the efficiency of the reduction gears could be slightly improved.

3. Axial Piston Motor [11]

a. Specifications

Weight of power Source: not specified.

Weight of Prime Mover:	0.91 kg (2 lb) estimated.
Input Requirements:	14 478 990.12 N/m^2 (2100 psig) gas from 233° to 1310°K (-40° to 1900°F) at approximately 0.0015 kg/sec (0.0034 lb/sec) for approximately 418 W (0.56 hp) output at 7000 rpm. Composition of gas is unspecified.
Type of Power Source:	unspecified type of gas generator.
Type of Prime Mover:	bent axis type axial piston motor. These figures are estimated from a 4117 W, 1.68 kg (5.6 hp, 3.7 lb) unit.

b. Computations

If we again assume a molecular weight of 11 and 1.247 m^3/kg (20 SCF/lb) of gas generator, we see that we obtain 0.0031 m^3/sec (0.111 SCF/sec) or 0.0025 kg (0.0055 lb) of gas generator per second. For 418 W (0.56 hp) and 2.27 kg (5 lb), we get 379 714 W-sec (509 hp-sec). Again, this does not look favorable compared to electrical power.

4. Advanced Electric Tool

If we consider the additional advantages that fuel cells provide over batteries, we see that electrical tools can offer significant weight and safety advantages over other systems. As an example, an Apollo type fuel cell has a power density of approximately 880 W-hr/kg (400 W-hr/lb) as opposed to the best silver zinc battery's maximum of 220 W-hr/kg (100 W-hr/lb). The actual batteries used in the minimum reaction tool have a power density of 71.7 W-hr/kg (32.6 W-hr/lb). In addition, a motor that is lighter than off-the-shelf items can be developed.

5. Other Power Sources

While the thermite-fueled steam generator [5], the monopropellant powered impulse device [6], and the cartridge-driven impact devices [7] all have high power-to-weight ratios, none of them includes a device to convert the power into rotary motion. Since this is probably the main source of inefficiency, it is very difficult to assign a realistic total power-to-weight ratio.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of existing and proposed space tool power sources, the advanced electrical power source offers significant safety and power/mass advantages over any other proposed system. This result is primarily due to difficulty in converting the tremendous thermal energy available in existing monopropellants into useful rotational mechanical power and the difficulty in containing the toxicants generated from tool use.

We recommend that emphasis be placed upon developing a purely electrical rotary driven tool system for space use, at least until a new power system is proposed with a significantly better power to weight ratio and safety factor than a brushless dc electrical unit using batteries and fuel cells. We must bear in mind that only electrically driven devices are suitable for use within the spacecraft interior, and that any other tool power system must also include provisions for electrical operation within the spacecraft.

Some of the types mentioned in the classification section have not been commercially developed; however, none of the types listed should be difficult to develop if their use is deemed necessary.

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APPROVAL

SPACE POWER TOOLS

By

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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R-ME-MW
Mr. Parks

R-ME-T
Mr. Franklin

R-ME-RE
Mr. Peck (6)

R-AS-VO
Dr. Hilchey (5)

R-EO-F
Mr. Lake

R-EO-R
Mr. Miles

MS-IP (2)

PAT
Mr. L. D. Wofford, Jr.

I-RM-M
MS-H
MS-T (6)
MS-IL (8)

R-ME-A
Mr. Nowak

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